

MISR Calibration and Implications for Low-Light-Level Aerosol Retrieval over Dark Water

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ABSTRACT

Studying aerosols over ocean is one goal of the Multiangle Imaging Spectroradiometer (MISR) and other spaceborne imaging systems. But top-of-atmosphere equivalent reflectance typically falls in the range of 0.03 to 0.12 at midvisible wavelengths and can be below 0.01 in the near-infrared, when an optically thin aerosol layer is viewed over a dark ocean surface. Special attention must be given to radiometric calibration if aerosol optical thickness, and any information about particle microphysical properties, are to be reliably retrieved from such observations. MISR low-light-level vicarious calibration is performed in the vicinity of remote islands hosting Aerosol Robotic Network (AERONET) sun- and sky-scanning radiometers, under low aerosol loading, low wind speed, relatively cloud free conditions. MISR equivalent reflectance is compared with values calculated from a radiative transfer model constrained by coincident, AERONET-retrieved aerosol spectral optical thickness, size distribution, and single scattering albedo, along with in situ wind measurements. Where the nadir view is not in sun glint, MISR equivalent reflectance is also compared with Moderate Resolution Imaging Spectroradiometer (MODIS) reflectance. The authors push the limits of the vicarious calibration method's accuracy, aiming to assess absolute, camera-to-camera, and band-to-band radiometry. Patterns repeated over many well-constrained cases lend confidence to the results, at a few percent accuracy, as do additional vicarious calibration tests performed with multiplatform observations taken during the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) campaign. Conclusions are strongest in the red and green bands, but are too uncertain to accept for the near-infrared. MISR nadir-view and MODIS low-light-level absolute reflectances differ by about 4% in the blue and green bands, with MISR reporting higher values. In the red, MISR agrees with MODIS band 14 to better than 2%, whereas MODIS band 1 is significantly lower. Compared to the AERONET-constrained model, the MISR aft-viewing cameras report reflectances too high by several percent in the blue, green, and possibly the red. Better agreement is found in the nadir- and the forward-viewing cameras, especially in the blue and green. When implemented on a trial basis, calibration adjustments indicated by this work remove 40% of a 0.05 bias in retrieved midvisible aerosol optical depth over dark water scenes, produced by the early postlaunch MISR algorithm. A band-to-band correction has already been made to the MISR products, and the remaining calibration adjustments, totaling no more than a few percent, are planned.

1. Introduction

The importance of retrieving aerosol optical thickness (AOT) and aerosol properties over dark water first drew attention when it was recognized that mineral dust from source regions in the Sahara Desert is regularly transported across the Atlantic Ocean and deposited in the Caribbean (reviewed by Prospero et al. 1983). Subsequent measurements identified significant transoceanic material redistribution of Asian dust and pollution as well (e.g., Clarke et al. 2001; Gao et al. 2001). In addition to material transports, the global-scale direct and indirect radiative impact of aerosols cannot be assessed adequately without a good under-

standing of the over-ocean contribution. It is estimated that top-of-atmosphere (TOA) reflected solar radiation flux varies with midvisible optical depth at a rate between 10 and 60 W m⁻² per AOT, depending on aerosol type and other environmental attributes (e.g., Penner et al. 1994). To resolve total aerosol direct radiative forcing of a few watts per meters squared over ocean, needed to assess aerosol climate impacts, AOT must be retrieved to an accuracy of about 0.01 or 0.02.

The Multiangle Imaging Spectroradiometer (MISR) is one of a new generation of instruments designed to observe the earth's environment globally (Diner et al. 1998a). The instrument was launched into polar orbit on 18 December 1999, aboard the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) *Terra* spacecraft. MISR makes near-simultaneous measurements at nine view angles spread

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out in the forward (f) and aft (a) directions along the flight path, at $\pm 70.5^\circ$ (cameras Df and Da), $\pm 60.0^\circ$ (Cf and Ca), $\pm 45.6^\circ$ (Bf and Ba), $\pm 26.1^\circ$ (Af and Aa), and nadir (An), in each of four spectral bands centered at 446, 558, 672, and 866 nm. MISR obtains global coverage, to $\pm 82^\circ$ latitude, about once per week, with a spatial sampling rate as fine as 275 m at all angles. The instrument systematically covers a range of air mass factors from 1 to 3, and in midlatitudes, samples scattering angles extending from about 60° to 160° . Such data can provide greater sensitivity to AOT than single-view measurements, especially over bright surfaces (Martonchik et al. 2004), over land in general (Abdou et al. 2005; Kahn et al. 2005), and for situations where the AOT is very low (Kahn et al. 1998). The data also contain considerable information about particle size and shape, particularly over dark surfaces (Kahn et al. 2001a; Kalashnikova et al. 2005).

However, early postlaunch comparisons between MISR-retrieved midvisible AOT and near-simultaneous, surface-based sun photometer observations reveal a systematic offset: the MISR AOT values are higher by about 0.05, in comparisons for dark water sites globally (Kahn et al. 2005). MISR measurements coordinated with airborne sun photometer observations during the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) campaign in summer 2001, under carefully monitored conditions, produce similar results (Redemann et al. 2005). Particle models and other assumptions in the aerosol retrieval algorithm may contribute to the discrepancy, as well as physical differences between the forward-scattering sun photometer and back-scattering satellite observations, and uncertainties in the sun photometer measurements themselves. Evaluating and refining MISR's radiometric calibration are necessary first steps toward understanding these differences and realizing the full potential of the MISR measurements for this application.

Global average midvisible column AOT is near 0.15, and away from source regions and plumes, column AOT is typically 0.07 or less (e.g., Smirnov et al. 2002; Husar et al. 1997). Over dark surfaces, such small aerosol loading produces TOA equivalent reflectances below 0.07 at midvisible wavelengths. Simulation of an aerosol mixture for which medium, spherical, nonabsorbing particles contribute 75% to the midvisible AOT of 0.05, 15% from black carbon and 10% from cirrus, over dark water, offers a representative case. The equivalent reflectance is 0.05 in the MISR red (672 nm), 0.02 in near-infrared (866 nm) channels for the 70° forward view, and 0.02 and 0.008 for the red and near-infrared bands in the nadir view. To achieve sensitivity to AOT changes of 0.02 for such cases, a radiometer must reliably measure equivalent reflectance to 0.005 or better. (In this paper, we use decimal notation for absolute reflectance and percent for relative reflectance differences.)

Calibrating an orbiting sensor to this accuracy is at the cutting edge of current capabilities and is beyond

what could be achieved for previous generations of satellite instruments. Early postlaunch MISR calibration efforts concentrated on higher reflectance levels, using a combination of preflight, onboard, and field vicarious calibration data (Bruegge et al. 1996; Bruegge et al. 1998; Bruegge et al. 2002; Chrien et al. 2002). For low light levels, the early work followed the traditional approach of extrapolating linearly to zero the calibration obtained for 15%–30% equivalent reflectance. The resulting low-light-level absolute calibration uncertainty is reported as about $\pm 5\%$ (Bruegge et al. 2002).

In this paper we undertake vicarious calibration aimed at characterizing MISR low-light-level radiometric performance in the reflectance range critical for aerosol retrieval over dark water. The challenge of this effort is to reduce comparison-data uncertainties as much as possible, and then to assess their magnitudes fairly. Fifteen events between 2000 and 2002, when MISR acquired data coincident with operating Aerosol Robotic Network (AERONET) surface-based sun-photometer stations, are at the heart of this study. AERONET offers multiple instruments and multiple events, extending over a variety of surface and atmospheric conditions (Holben et al. 1998). The 15 events chosen here cover a range of midvisible AOT from below 0.03 to 0.3 and equivalent reflectance from about 0.02 to 0.08 in the MISR red channel. For a vicarious calibration study, such diversity helps build confidence in the patterns that emerge; to obtain quantitative conclusions, we can afford to select the best-constrained cases, since MISR radiometric performance is very stable (Bruegge et al. 2002). To further test the observed patterns, we also study coincident MISR, AirMISR, and field data taken on 2 days during the CLAMS campaign.

We use AOT, aerosol size distribution, and particle single scattering albedo (SSA) retrieved from AERONET data to constrain simulations of TOA equivalent reflectance at all nine MISR view angles and four wavelengths and compare the calculated reflectances with corresponding values from the MISR calibrated and georectified radiance product (MISR L1B2, version F03_0022, is used throughout this paper, available online from the NASA Langley Atmospheric Sciences Data Center at <http://eosweb.larc.nasa.gov/>). We examine band-to-band, camera-to-camera, and absolute radiometric performance. In cases for which the nadir view is not in sun glint, we also compare with coincident reflectances acquired by the multispectral, nadir-viewing Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, which flies on the *Terra* satellite with MISR. These comparisons allow us to establish the MISR reflectance scale to an absolute accuracy of a few percent, in the equivalent reflectance range of interest. A separate paper (Bruegge et al. 2004) summarizes calibration constraints available from MISR preflight, onboard, and lunar calibration analyses, along with additional comparisons between coincident MISR and MODIS scenes.